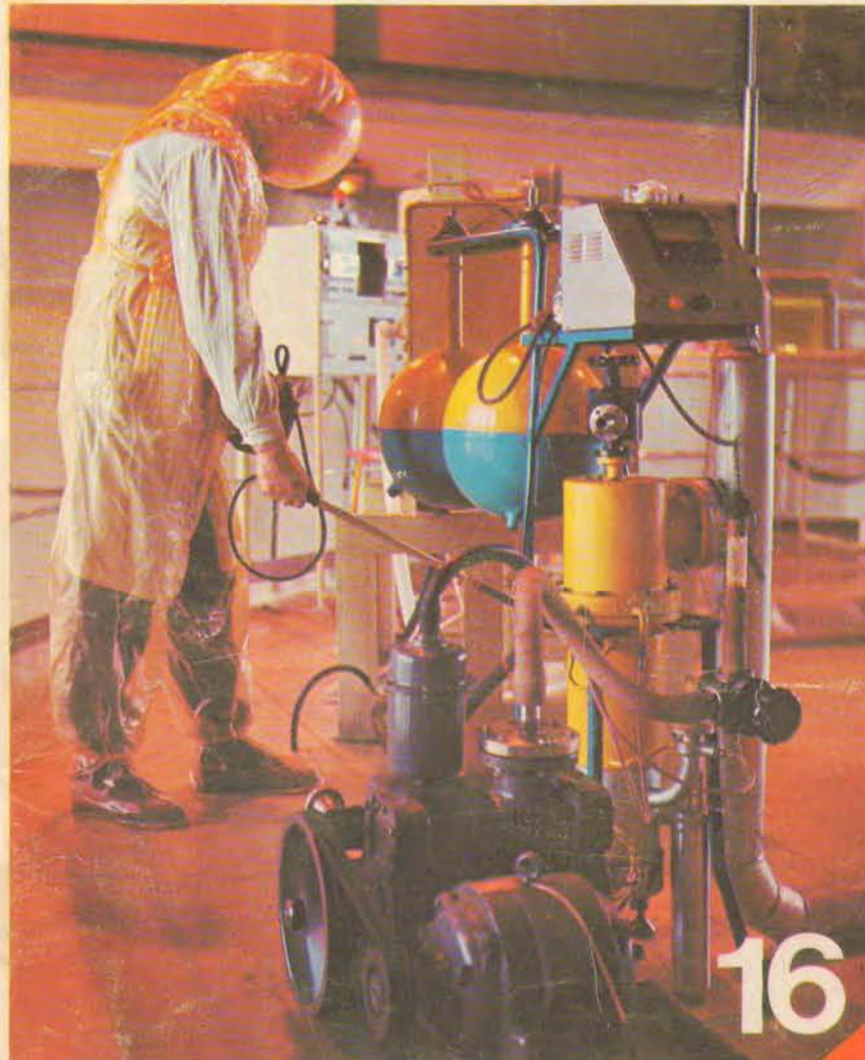
BASIC SCIENCE SERIES



16

ATOMS

REVISED EDITION

CONTENTS

MATTER

Look at all the things around us: chairs, desks, cupboards, papers and pens in our classroom; motor cars, bicycles and buses in the streets; trees, plants and animals in the countryside; birds, aeroplanes and clouds in the sky; fishes, seaweeds and corals in the sea; stars, the moon and the sun in outer space. These and all other things including the human body, are examples of **matter**. Matter is anything that takes up **space** and has **weight**.

Everything in this picture, including the page it is printed on, are examples of matter.

WHAT IS MATTER MADE OF?

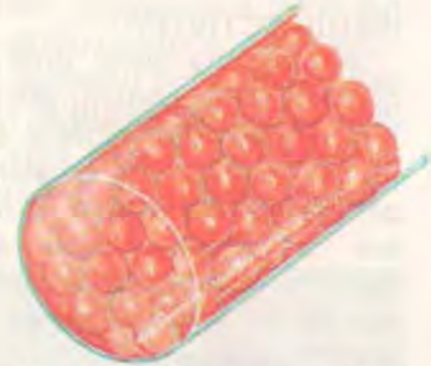
Since ancient times, learned men or **philosophers** have thought about matter and what it is made up of. One group of philosophers thought that matter was made up of a substance called 'hyle'. Another group of philosophers said that matter was made up of four substances namely earth, water, air and fire. A third group believed that matter was made up of very tiny particles which were too small to be seen. These particles were so small that they could never be further divided into smaller particles. They gave the particles the name **atoms** which means 'those which cannot be divided'. The difference between the various kinds of atoms and the ways in which they were joined were supposed to result in the different kinds of matter.

All these ideas arose purely from the mind and were not based on investigation. For many years, people believed in the second idea. But actually it is the third idea that is nearer to our present concept of matter.

DALTON'S ATOMIC THEORY

In the early nineteenth century, **Dalton**, an English school teacher, stated in this **atomic theory** that matter was made up of tiny, indivisible particles, which he also called atoms. His laboratory work showed him that atoms could neither be divided into smaller parts nor could they be destroyed. He pictured matter as being

Dalton thought that matter was made up of tiny solid spherical atoms.



made up of tiny solid spherical atoms. Today the idea of the atoms has been accepted. But further work has shown that contrary to Dalton's findings, atoms are made up of even smaller particles.

THE DISCOVERY OF THE ELECTRONS

Towards the end of the nineteenth century, **J.J. Thomson**, an English physicist, studied the behaviour of an electric current passing through a tube, from which air had been removed. This tube is known as a **cathode ray tube**. He found that the current consisted of negatively charged particles which are now called **electrons**. His experiments led him to conclude that the electrons came from the inside of atoms. Other scientists were able to find out the mass (total amount of matter) of an electron. This mass was only a small fraction of that of the lightest atom, showing an electron was even smaller than an atom.

RADIOACTIVITY

Around the same time some scientists discovered that certain atoms were capable of breaking up into smaller atoms by themselves. In the process of breaking up they give off particles smaller than themselves. Such atoms are called **radioactive atoms**. One kind of particles given off by these radioactive atoms is known as **alpha particles**.

Ernest Rutherford

Niels Bohr

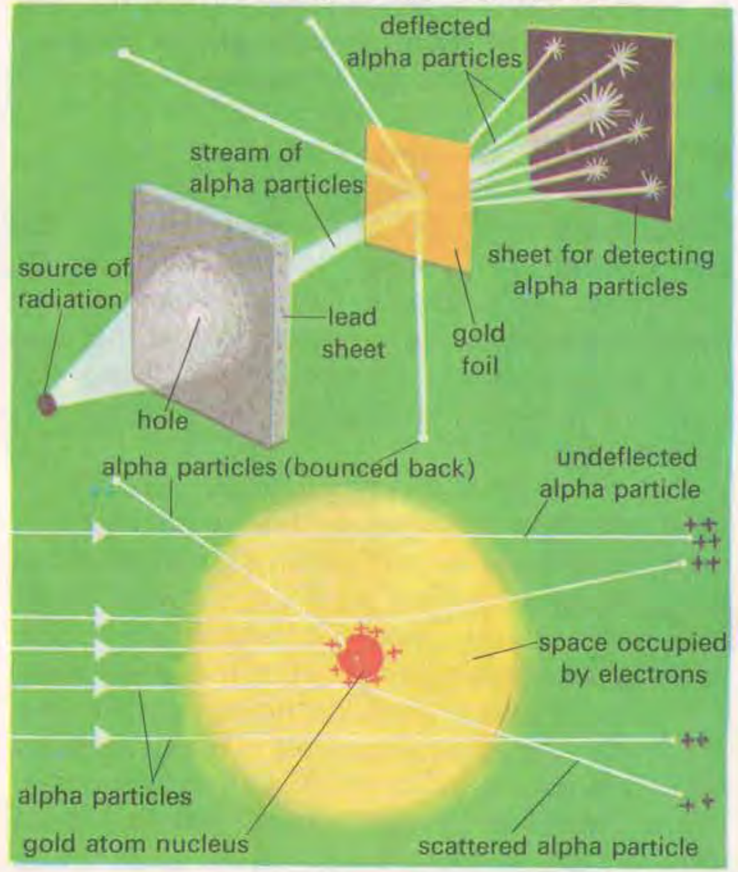
They contributed towards our understanding of the atom.

DISCOVERY OF THE NUCLEUS

Around 1911, **E. Rutherford**, a New Zealand-born physicist, sent a stream of fast moving alpha particles towards a very thin piece of gold foil. To his surprise he found that most of the tiny alpha particles passed straight through the gold foil as though it was not there. Only a few particles were deflected or bounced back. Why do you think this happened? The reason why most of the particles passed straight through without their path being blocked, was that the atoms in the gold foil were not solid, but consisted mainly of empty space. However at

the centre of each atom, there was a small but heavy mass of matter against which a few alpha particles collided and bounced back. Rutherford called this heavy mass at the centre of the atom the **nucleus**. It was then found that the atoms of all other substances too had a nucleus.

Rutherford's gold foil experiment



MODELS OF ATOMS

What does an atom look like? No one really knows yet. Scientists make guesses about what atoms are like by studying their behaviour. From these guesses they build models.

There are many different kinds of models of an atom and it must be kept in mind that none of these models might really look like the real atom. But all of them, in one way or another, help us to understand the behaviour of atoms.

STRUCTURE OF THE ATOM

We have learned that atoms contain particles called electrons. Two other kinds of particles also present in the atoms are the **protons** and **neutrons**. An electron has a negative (−) electric charge while a proton has a positive (+) electric charge. But a neutron does not have any electric charge and is therefore electrically neutral.

One important property of particles which have electrical charges is that particles with opposite charges attract each other while those with the same charges repel each other. Therefore a positively charged particle attracts a negatively charged particle. On the other hand positively charged particles repel one another. The same applies to negatively charged particles also. In a normal atom, there is an equal number of electrons and protons. As a result, an atom as a whole, is electrically neutral.

The protons and the neutrons are closely packed in the centre of an atom. Together they form the nucleus. The number of protons in the nucleus of the atom is known as the **atomic number**. The total number of protons and neutrons within the nucleus is known as the **mass number**. Once the two numbers are known we can easily find out the number of neutrons in a nucleus by using the equation:

number of neutrons = mass number − atomic number

Some common atoms

Name of Atom	Symbol	Atomic Number (no. of protons)	Number of neutrons	Number of electrons	Mass Number (no. of protons and neutrons)
Hydrogen	H	1	0	1	1
Helium	He	2	2	2	4
Lithium	Li	3	4	3	7
Carbon	C	6	6	6	12
Oxygen	O	8	8	8	16
Sodium	Na	11	12	11	23
Chlorine	Cl	17	18	17	35
Calcium	Ca	20	20	20	40
Iron	Fe	26	30	26	56
Cobalt	Co	27	32	27	59
Tin	Sn	50	69	50	119
Gold	Au	79	118	79	197
Uranium	U	92	146	92	238

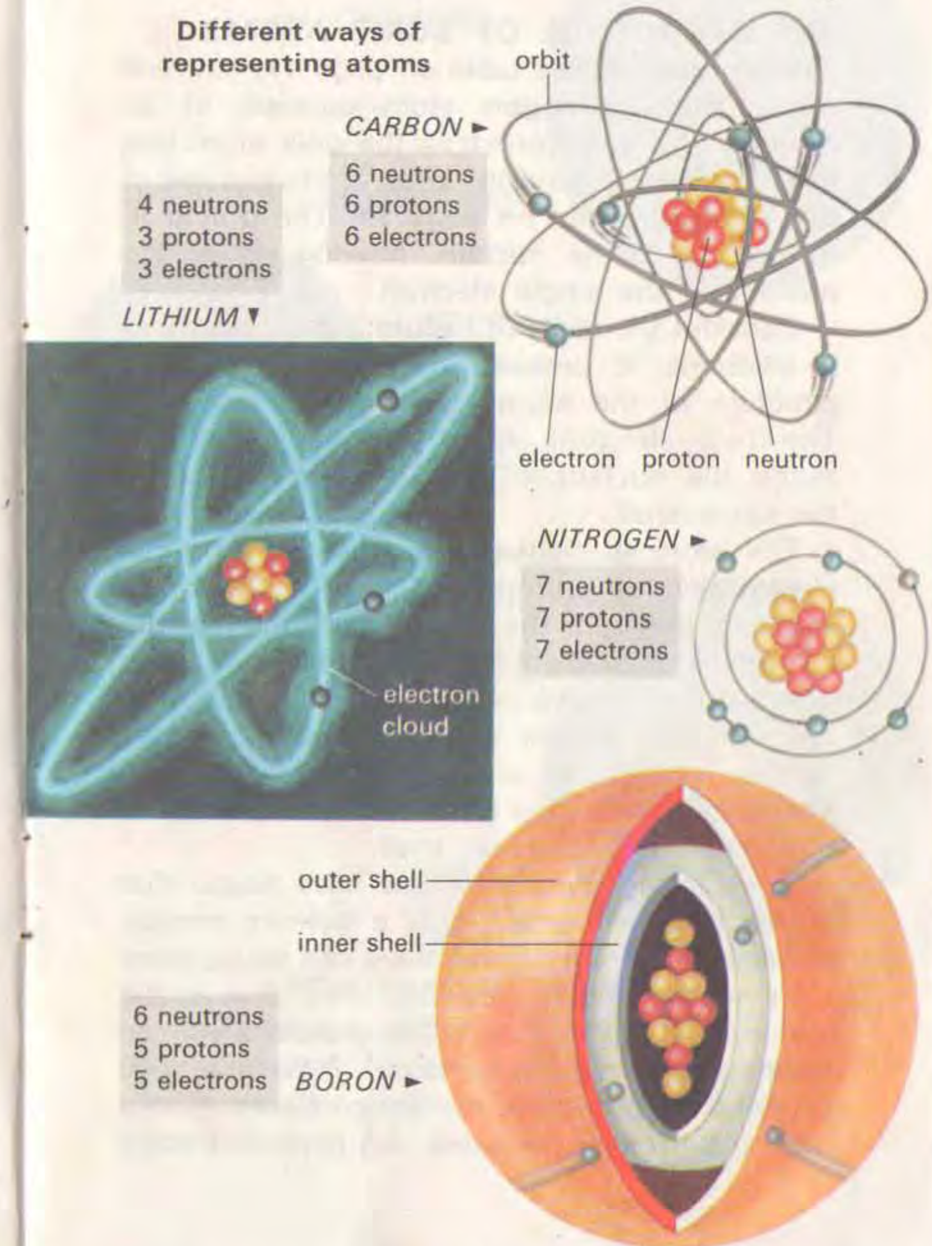
The electron is the lightest of the three particles — so light when compared with the weight of the proton or the neutron that it can be considered as having no weight. However it has a great deal of energy and moves very fast.

The atom consists mainly of empty space, as Rutherford's gold foil experiment showed. The nucleus occupies a very small portion of this space while the electrons are distributed around the nucleus in places called **shells** or **energy levels**. It has been found that electrons form a sort of 'cloud' around the nucleus. Because the idea is not easy to imagine we shall follow the model put forth by **Niels Bohr**, a Danish scientist, in 1913. This model is simpler and therefore more useful for our present level of understanding. In this case, the electrons are pictured as moving round the nucleus in **orbits**, similar to the way planets move round the sun.

DIFFERENT KINDS OF ATOMS

There are over a hundred different kinds of atoms and the difference between each kind lies in the total number of electrons, protons and neutrons each atom has. Each kind of atom has a name. Scientists write the names of every atom in a short form. These short forms are called **symbols**. The table on page 11 shows the names of some of the atoms, their symbols, the atomic numbers, the number of neutrons, the number of electrons and the mass number.

Different ways of representing atoms



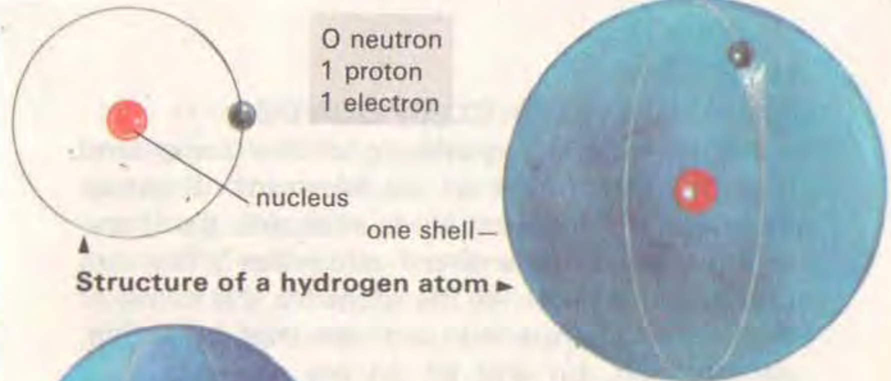
THE STRUCTURE OF SOME ATOMS

If you look at the table on page 11, you will notice that **hydrogen** atom consists of an electron and a proton. It is the only atom that does not have a neutron. Look at the pictures of the hydrogen atom on page 15. The proton in the centre is the nucleus. Moving round the nucleus is the single electron.

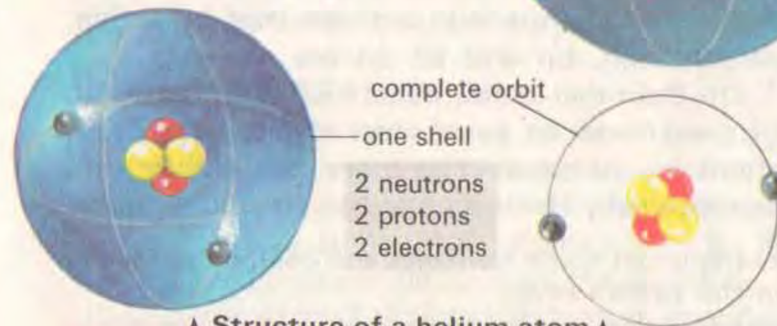
Consider the atom of **helium**. Each atom has 2 electrons, 2 protons and 2 neutrons. The structure of the atom is shown on page 15. The two electrons move at equal distances round the nucleus. They are said to orbit in the same shell.

The atom of **lithium** is made up of three electrons, three protons and four neutrons. As you can see from the picture on page 15, the arrangement is slightly different. The nucleus is made up of three protons and four neutrons. As with the helium atom, two electrons are orbiting in the same shell. But the third electron is whirling at a greater distance from the nucleus. It is orbiting in another shell.

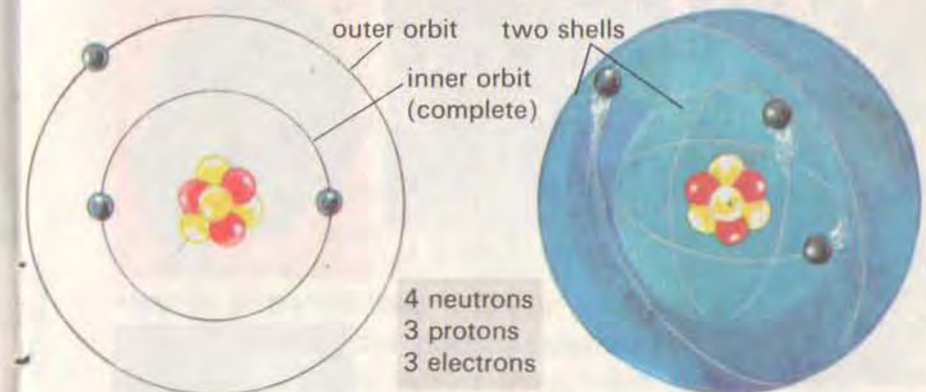
From experiments scientists have found that each shell can contain only a definite number of electrons. For example, there can be no more than two electrons in the first shell, that is, the one nearest the nucleus. The second shell can only contain eight electrons. When a shell contains the maximum number of electrons, it is said to be full or complete. An important point to note is that it is the electrons present in the outermost shell that take part in most **chemical reactions**. We shall learn about chemical re-actions later.



▲ Structure of a hydrogen atom ►



▲ Structure of a helium atom ▲



▲ Structure of a lithium atom ▲

ELEMENTS AND COMPOUNDS

Matter which is made up of the same kind of atoms is known as an **element**. Suppose there are 103 different kinds of atoms, then how many elements are there altogether? We can also use the name of the atom for the name of the element. Thus we can say that hydrogen, carbon, iron, tin and so on are elements.

On the other hand, matter which is made up of two, three or even more different kinds of atoms joined together as a group is known as a **compound**. For example, two hydrogen atoms

Examples of some elements and compounds found in the Earth's crust.

compound of nickel ▲

copper containing mineral ▲

◄ diamonds (carbon)

gold ▼

compound of calcium ►

may combine with one oxygen atom to form a compound called **hydrogen oxide**, which is commonly known as water. Common salt is **sodium chloride**, a compound formed from the elements sodium and chlorine. Can you imagine how many compounds can be formed by the different combinations of the various elements?

CHEMICAL REACTIONS

Now with our knowledge of the make-up of the atoms, we want to see how combination between atoms takes place. A chemical reaction is said to take place when atoms combine. We have already noted earlier that the electrons in the outermost shell of the atom play an important part in chemical reactions. This is because in most cases, it is the outermost shell of an atom that is not completely filled with electrons.

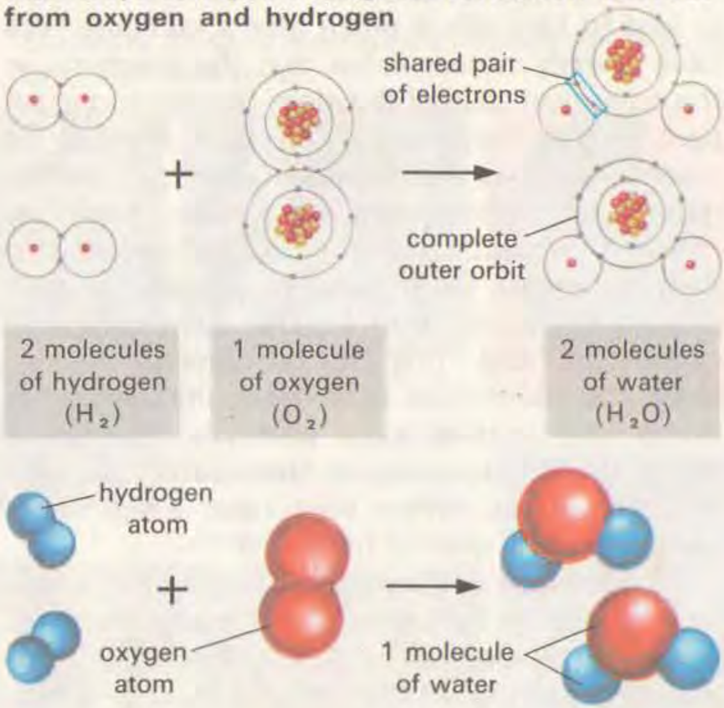
When two such atoms react, the electrons in their outermost shells tend to arrange in such a way that each atom has its outermost shell completely filled. This can be done by — (*a*) sharing some of their outer electrons with other atoms, (*b*) getting extra electrons from other atoms or (*c*) donating all their outer electrons to other atoms. When they have a full outer shell, they are said to be stable.

Take the case of the hydrogen atom. It has only one electron in the shell. How many electrons more are needed to complete this shell? The answer is one. What happens if this atom comes

across another hydrogen atom which also needs one more electron. It would then be natural for the two atoms to combine together by sharing their electrons so that each has a full outer shell. These two atoms are now bound together as a group by electron sharing. Such groupings of atoms are known as **molecules**. For example, hydrogen gas is made up of hydrogen molecules.

Let us now study a more complicated case — hydrogen and oxygen atoms. An oxygen atom

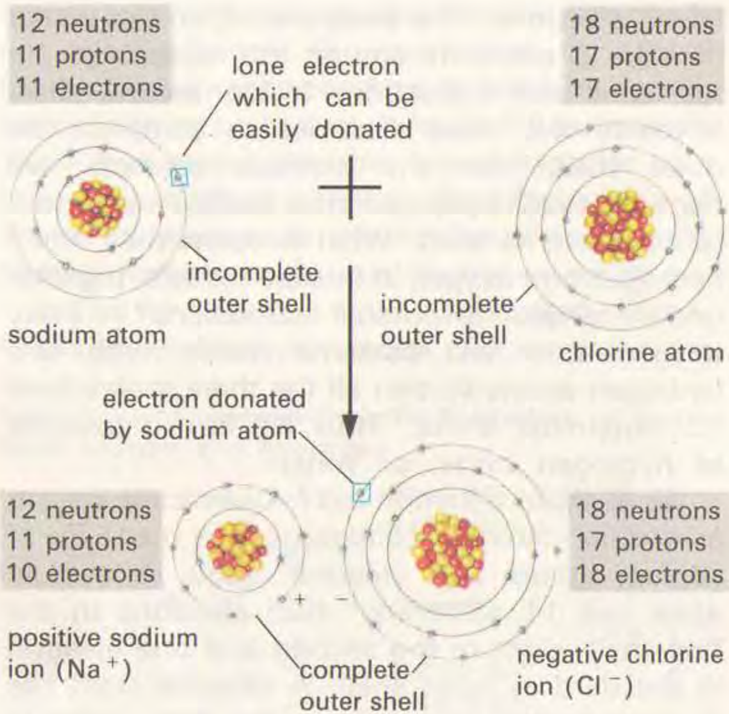
Two ways of representing the formation of water from oxygen and hydrogen



has 8 electrons. The electronic structure would then be 2 electrons around the nucleus in the first shell and 6 electrons in the second shell. It needs two more electrons to complete the outer shell. From the previous example, we know that each hydrogen atom needs one electron to complete its shell. What happens then when hydrogen and oxygen atoms are brought together under certain favourable conditions? Every oxygen atom will combine readily with two hydrogen atoms so that all the three atoms have full outermost shells. Thus we have molecules of hydrogen oxide, or water.

What about common salt? Chemically known as sodium chloride, common salt is made up of sodium atoms and chlorine atoms. A sodium atom has 11 electrons: two electrons in the first shell, eight in the second and one electron in the third or outer shell. A chlorine atom has seventeen electrons: two in the first, eight in the second, and seven in the third shell.

The sodium atom must do one of two things to achieve stability: to lose one electron from its third shell, or to gain seven electrons to fill the third shell. Which is easier? To lose one electron, of course. When it does so, the total number of protons in the atom would be greater than the total number of electrons. As a result, the atom as a whole is positively charged. This kind of positively charged atom is known as a **positive ion.**



Two ways of representing the formation of common salt from sodium and chlorine

On the other hand, the easier way for the chlorine atom to achieve stability is to gain one electron rather than to lose the seven in its outermost shell. Naturally it will accept the electron readily given off by the sodium atom. This additional electron makes the atom as a whole negatively charged and the atom is now known as a **negative ion**.

How do you think the positive and negative ions will behave towards each other? They will be attracted to each other because of their electrically opposite charges and will be held together by this electrical force. This is how sodium chloride is formed from sodium and chlorine.

THE NUCLEUS

So far we have studied the behaviour of the electrons in atoms and have seen how they are responsible for some of the chemical reactions. We shall now turn our attention to the behaviour of the nucleus.

Earlier we have noted that the nucleus of an atom consists of protons and neutrons very tightly packed together in the centre of the atom. Protons are positively charged particles while neutrons have no electrical charges. We know that like charges repel. So, a question arises. Why are the protons not repelled by one another thereby resulting in the breaking up of the nucleus?

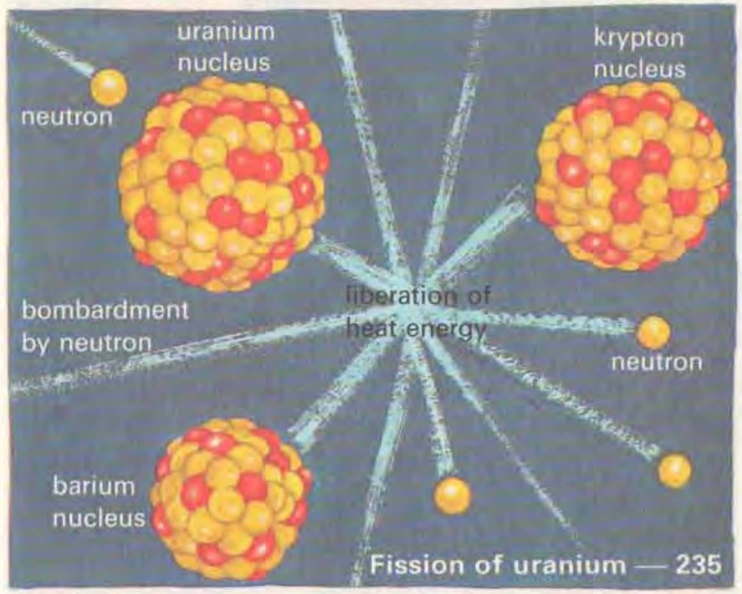
The answer lies in the existence of another kind of force that is stronger than the repulsive force between the protons. This force is called the **nuclear force**. It is this powerful nuclear force that binds the protons so closely together. This force comes from a form of energy called the **binding energy** of the nucleus. How does this energy come about? According to a very important discovery of **A. Einstein**, a German-born physicist, mass can be changed to energy and similarly energy can be changed to mass. It was found that the mass of the nucleus is slightly less than the total mass of the protons and neutrons which made up the nucleus. The difference in mass has been converted to energy to keep the protons in the nucleus together.

SPLITTING OF THE NUCLEUS

The protons and neutrons in the nuclei of most common atoms are strongly held together. The nuclei of these atoms are said to be stable. On the other hand, the nuclei of some atoms especially the bigger ones like uranium, are not so stable. This is partly due to the large number of protons and neutrons present in their nuclei.

Large unstable nuclei have a tendency to break up, on their own, into smaller nuclei. They can also be made to break up or split into smaller nuclei if they are bombarded with very small particles.

The splitting of the nucleus of an atom is called **fission**. But what is the importance of fission? When fission of, say, a uranium nucleus occurs, the nucleus splits up into smaller nuclei of other atoms, giving off neutrons and a large amount of **nuclear energy** in the form of heat. The energy given off from the fission of just 1 kilogram of uranium is equivalent



Fission of uranium — 235

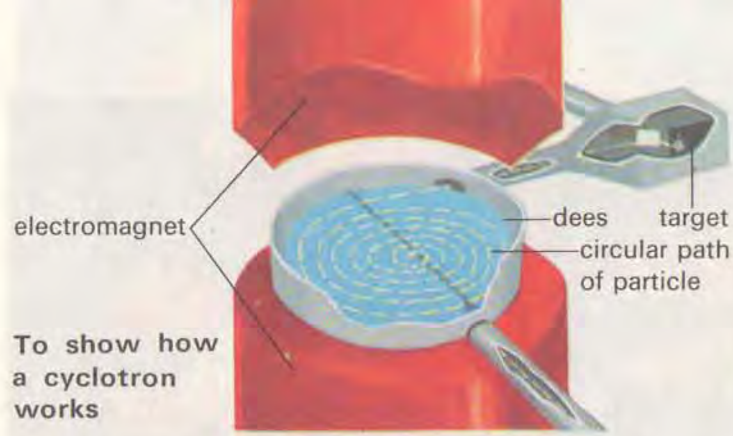
to the energy we can obtain from burning over 900,000 kilograms of coal! Just imagine what a tremendous amount of energy we can get from the fission of atoms.

There are two different kinds of uranium. One is called uranium-238 i.e. uranium of mass no. 238, and the other uranium-235 i.e. uranium

of mass no. 235. Uranium-235 is less stable than uranium-238 and is therefore commonly used to produce nuclear energy by fission.

What do scientists use to split the atoms? Normally they use neutrons, protons or alpha particles. These particles are used as a kind of atomic bullets. Neutrons are good atomic bullets because they do not possess any electrical charge. This is why they can penetrate and break up the positively charged nuclei more easily than the protons or the alpha particles (made up of 2 protons and 2 neutrons). On the other hand, if the positively charged protons or alpha particles are used they will be repelled by the positively charged nucleus. However, in some experiments it is necessary to use protons and alpha particles as atomic bullets. In such cases the particles have to move very fast before they can penetrate the nuclei. A machine, called a **cyclotron**, is used to make the particles move very fast. The cyclotron consists of a pair of semicircular metal chambers called **dees**. These are mounted between the poles of a very powerful electromagnet.

A cyclotron

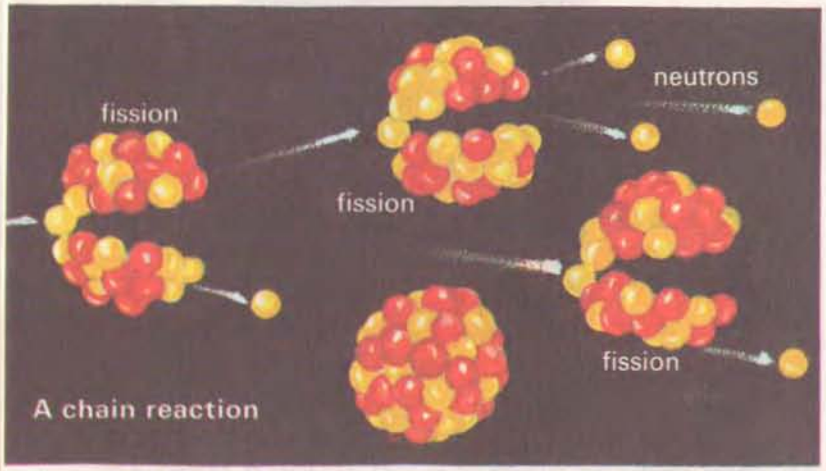


To show how a cyclotron works

Protons or alpha particles are released near the centre of one of the dees. They are made to travel in a circular path from the centre to the outer part of the dees. As they move round and round in the cyclotron, their speed increases. By the time they come out of the cyclotron, their speed has become nearly equal to that of light so that the protons or alpha particles can now penetrate right into the nuclei and cause fission to take place.

CHAIN REACTION

We have learned that when a uranium atom is hit by a neutron, it breaks up into smaller atoms, giving off neutrons and energy. What happens when there are many uranium atoms around? The neutrons given off by the first uranium atom will strike a few more uranium atoms nearby. These neutrons will split the atoms and release more neutrons to strike even more uranium atoms. This rapid process is repeated again and again, and in a very short time



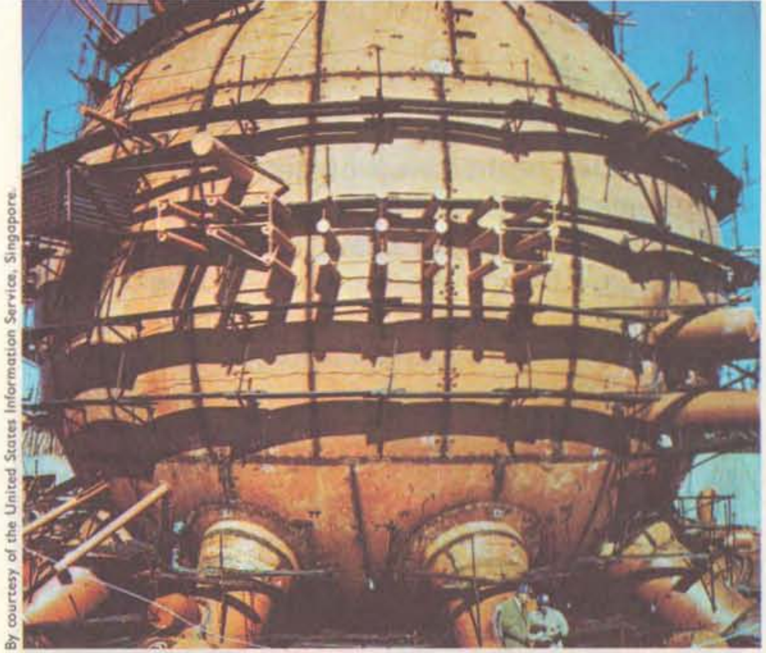
A chain reaction

millions of uranium atoms would have undergone fission. This is called a **chain reaction**.

If a chain reaction were to take place too quickly as in the case of a lump of uranium-235, the energy given off would be so great that a huge explosion will take place. The atomic bomb works on this principle.

Luckily, scientists have learned how to slow down and control the speed of fast nuclear chain reactions. The place where such a reaction can be controlled is known as a **nuclear reactor**.

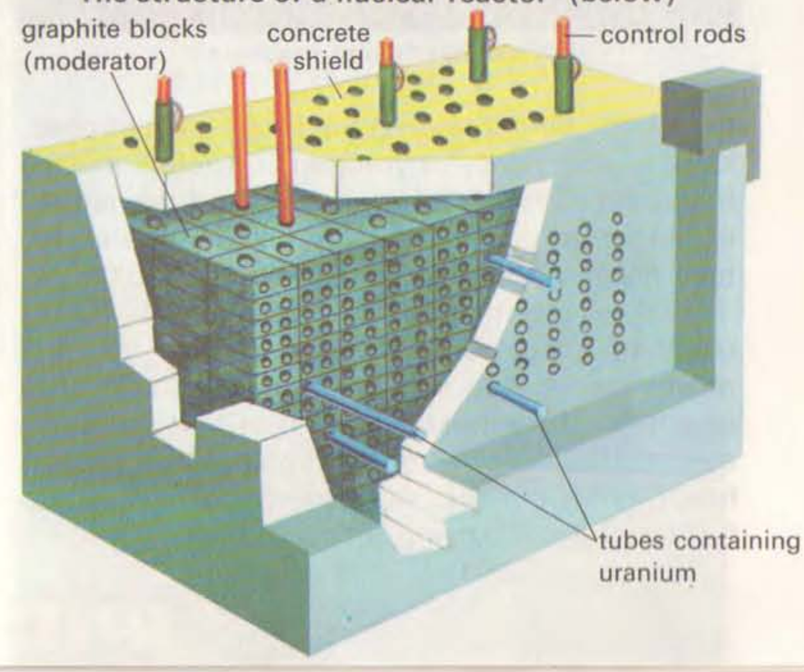
How is a nuclear chain reaction controlled? It is controlled by surrounding the fissionable material, e.g. U-235, with a substance like **graphite** (a form of carbon), which is known as a **moderator**. This slows down the speed of the neutrons. Rods, made of neutron-absorbing material, are lowered into the nuclear reactor to act as a further control measure.



By courtesy of the United States Information Service, Singapore.

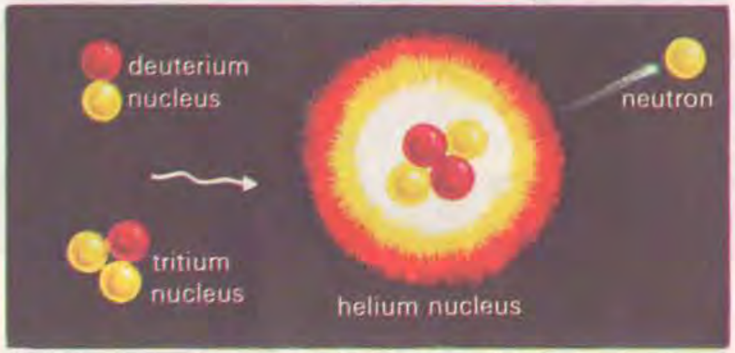
A nuclear reactor (above)

The structure of a nuclear reactor (below)



NUCLEAR FUSION

There is another way of getting energy from the nuclei of atoms. Instead of breaking down the unstable nuclei of heavy atoms, we can also get energy by joining together two light nuclei to make a heavier nucleus. This process is called **nuclear fusion**. Fusion of the nuclei of



A nuclear fusion reaction

deuterium and tritium (two forms of hydrogen, known as heavy hydrogen) results in the formation of the helium nucleus and the release of a neutron. This fusion reaction can only take place at temperatures above 30,000,000°C.

The explosion of a hydrogen bomb is the result of uncontrolled nuclear fusion. It is the most terrible weapon of war that Man has invented. Unfortunately scientists have not been able to find a way of controlling this nuclear fusion and put its vast source of energy to further the well-being of mankind.

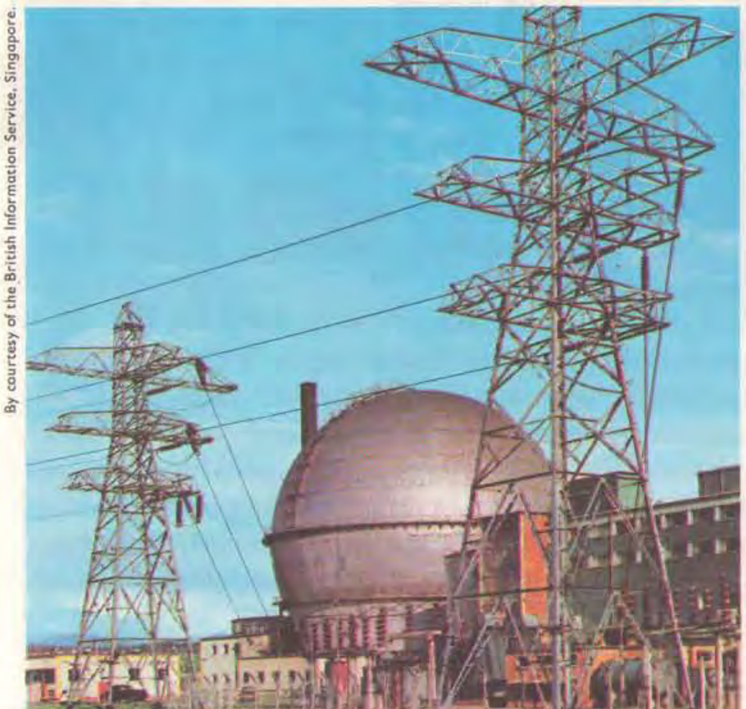
USES OF ATOMS

The study of atoms have brought about many uses which are beneficial to Man and some which are not. Some of these uses are given below.

1. *Source of Power:* Controlled nuclear fission can provide us with tremendous amounts of energy or power to do work. In the future this could be our main source of power once our present sources of energy like coal and petroleum are exhausted. Among other things, energy from fission is used to power submarines, ships and to generate electricity. In

A nuclear reactor and an electrical sub-station

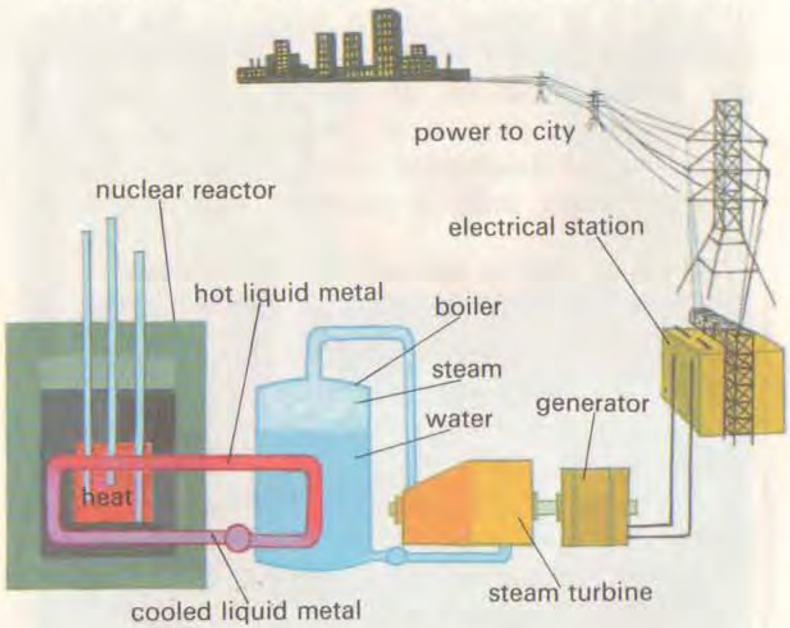
By courtesy of the British Information Service, Singapore.



the near future nuclear energy may be used to power rockets and spaceships.

How to get electricity from atoms: In an atomic power station there is a nuclear reactor, a boiler, turbines and generators. Fission of the

How nuclear energy is used to produce electricity



atoms takes place in the nuclear reactor. Much of the nuclear energy produced in the fission process is in the form of heat. The speed of the chain reaction is controlled carefully so that a steady supply of heat is produced. This heat is absorbed by a liquid metal, which then flows

through a pipe to a boiler containing water. The heat from the hot liquid metal changes the water to steam. The steam is then used to turn generators which produce electricity for our use at home and in factories.

2. *Medical Applications:* Radioactive radium or cobalt is used to treat early stages of cancer. The radiation is used to kill the cancer cells thus putting a stop to the growth of the cancerous tissue.

3. *Carbon Dating:* Like uranium, carbon has two kinds of atoms. One of them is radioactive, that is, it breaks up continuously. As time passes the amount of radioactive carbon in an object becomes less and less. By finding the percentage of radioactive carbon remaining in an object, scientists are able to calculate the age of an object. This method of determining age is called **carbon dating**. It is by carbon dating that scientists are able to find out the age of objects which **archaeologists** (people who study things from a prehistoric period) dig up from the ground.

4. *Tracer Research:* Scientists are interested to know more about **biochemical reactions**, that is, reactions that take place inside a living cell. By using chemicals with radioactive atoms, the path of the chemicals in the cells can be traced. The radioactive atoms used in this way are called **tracers** and through them biochemical reactions can be studied.

An atomic explosion can cause an unlimited amount of harm.

5. *Weapon:* The atomic and hydrogen bombs are examples of how nuclear energy can be used for destructive purposes. Their power of destruction is beyond description.

CONCLUSION

The study of atoms is a fascinating subject that has yet to be exhausted. The more the scientists examine the atoms, the more mysteries are uncovered. Today, besides the electrons, protons and neutrons, many more particles have been discovered. People are still in doubt as to the actual basic unit of matter so that they are still asking the question Man used to ask in the olden days: What is matter made of? An American scientist, called **Gell-Mann**, has postulated the existence of **quarks** as the basic building block of all matter. These are supposed to have electrical charges. The question as to whether quarks really exist or not is left to future scientists to find out.